

## MAGNETICALLY INDUCTIVE FLOW METER

## CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is the US National Stage of International Application No. PCT/DE2003/003670, filed November 6, 2003 and claims the benefit thereof. The International Application claims the benefits of German application No. 10252041.0 filed November 6, 2002, both applications are incorporated by reference herein in their entirety.

## FIELD OF THE INVENTION

[0002] The invention relates to a magnetically inductive flow meter having a measuring tube, an electrode array with electrodes disposed on opposite sides of said measuring tube transversally to a direction of flow therethrough, and a coil arrangement having at least one saddle coil whose axis extends transversally to the direction of flow and transversally to the electrode array and which has four sides, two first sides extending parallel to the direction of flow and two second sides extending in the circumferential direction of the measuring tube.

## BACKGROUND OF THE INVENTION

[0003] A moving electrically conductive fluid flowing through the measuring tube generates a voltage between the electrodes in the electrode array when the coil arrangement generates a magnetic field, with said magnetic field being oriented perpendicularly to the direction of flow.

[0004] The voltage is tapped perpendicularly to the direction of flow and perpendicularly to the magnetic field. The voltage on the electrode array is then dependent on, inter alia, the speed of flow, from which the rate of flow can in turn be inferred.

[0005] It is of some significance for the measuring accuracy of a flow meter of this type for the magnetic field to extend over the entire cross-sectional area of the measuring tube. One possible way to achieve this is to use a yoke or pole shoe. The coil then generates a magnetic field that will be distributed through the pole shoe and then extend substantially evenly over the cross-section of the measuring tube.

[0006] Pole shoes of this type require a certain amount of structural space, however. Saddle coils are for this reason often used whose shape is accommodated to that of the measuring tube. The coil arrangement as a rule has two saddle coils. Viewed from above, said saddle coils form in the broadest sense a rectangle two sides of which extend parallel to the direction of flow. The other two sides follow the curvature of the measuring tube. Said sides can also be arched or angled in the axial direction so that, viewed from above, the saddle coil resembles a hexagon, thus having the appearance of a diamond. Substantially satisfactory results can also be achieved using saddle coils of this type.

[0007] Problems will, however, arise if the diameter of the measuring tube is to be reduced. There will be an increase in measuring errors particularly in the case of diameters less

than, for instance, 50 mm. This is attributed to its not being possible to extend the saddle coils sufficiently far in the circumferential direction around the measuring tube. That is because the electrodes in the electrode array require a certain amount of structural space. As a rule, they also have a small terminal housing. The saddle coils' first sides parallel to the axis must leave said space free. The magnetic field consequently does not extend far enough toward the electrodes. As mentioned above, this results in inaccuracies or errors in the measurements.

#### SUMMARY OF THE INVENTION

**[0008]** The object of the invention is to improve the measuring accuracy for a measuring tube having a smaller diameter.

**[0009]** Said object is achieved in the case of a magnetically inductive flow meter of the type mentioned at the beginning by in each case locating between each first coil side and the measuring tube a magnetically conductive element that takes up a first part of the magnetic flux, with a second part of the magnetic flux from an area surrounded by the saddle coil bypassing the element.

**[0010]** The direction of the magnetic field is changed by means of the magnetically conductive element, specifically in the direction of the electrode. The magnetic field will then better fill the cross-section of the measuring tube. The measuring signal that can be tapped on the electrode array will then increase in intensity, as desired. This improvement in the measuring result is, however, achieved by deflecting only a part of the magnetic flux. The major part of the

magnetic flux in the area surrounded by the saddle coil remains undisrupted, which is to say it can spread through the cross-section of the measuring tube without being affected by a pole shoe or other flux-distributing element. Especially advantageous herein is that undesired leakages that can arise at the edge of a pole shoe practically do not develop. Added to this is the fact that the overall height of the saddle coil is virtually negligibly increased through the addition of the magnetically conductive element. The magnetically conductive element can be embodied as a relatively thin strip that will fit into a gap present as a rule in any event between the saddle coil and measuring tube. Said element is preferably located in the area where the electrodes are also located in the axial direction of the measuring tube.

[0011] The element preferably extends from an area on the inner edge of the first coil side and terminates between the first coil side and the measuring tube. The area enclosed by the saddle coil, which is to say the magnetic field extending parallel to the axis of the saddle coil, is virtually undisturbed by the element. The element is, however, able to redirect a part of the magnetic flux such that the magnetic field will extend into the vicinity of the electrodes in the electrode array. Considerable advantages can therefore be achieved without the need to accept any major disadvantages.

[0012] The element preferably has an angled section located from the inside against the first coil side. The inside is here the side opposite the other first coil side. The inside is therefore located in the interior of a revolution made by the turns of the saddle coil. Automatic positioning of the element

is made relatively easy by said section. The element is simply inserted "up to the stop" into the space between the measuring tube and coil or, expressed more precisely, the first side of the coil. The element will thereafter be correctly positioned.

[0013] Said section can be secured either to the coil side or to the measuring tube. Adhesive means, for example, can be used for this, in particular double-sided adhesive tape. The section thus then serves to position the element in several directions. Displacing of the element in the circumferential direction is for one thing avoided; its displacement in the axial direction is also reliably prevented by means of an adhesive securing means.

[0014] The element is preferably embodied as U-shaped with two arms and attached to the first coil side from inside. The element is thus embodied as a "clip", with one of its arms performing the actual magnetically conductive function that changes the direction of the field. The base of the U and the arm opposite the first-mentioned arm will then serve basically only to fasten the element to the first side of the saddle coil.

[0015] It is particularly preferred herein for the arms to be pretensioned toward each other. The clip will then have a spring effect. The clip will be fastened particularly well to the first side of the saddle coil through the spring effect of the arms.

[0016] The arm between the first coil side and the measuring tube is preferably longer transversally to the direction of

flow than the other arm. As mentioned above, the other arm serves chiefly to fasten the element to the first side of the saddle coil. This can also be reliably achieved by means of a geometrically smaller embodiment. Material is therefore saved through this embodiment.

**[0017]** The element preferably extends over the length of the first coil side in the direction of flow. The desired redirection of the magnetic field toward the part of the wall of the measuring tube in which the electrode is located is thereby effected throughout the axial length of the saddle coil.

**[0018]** The element preferably has a recess between its ends in the direction of flow. A satisfactory measuring result has also proved to be achievable using a recess of this type. The magnetic field will then be somewhat different in appearance. It will be spread in the axial direction, which is to say in the direction of flow. This is not of major significance, however, since the main objective is for the magnetic field to have the desired distribution in the area of the electrode array.

**[0019]** The element preferably has an undulating surface. It can also itself be undulated. With the undulating surface it is possible to secure the element between the first side of the saddle coil and the measuring tube.

**[0020]** The element is preferably made of soft magnetic iron. Soft magnetic iron has excellent properties for conducting magnetic fields.

**[0021]** The element can alternatively also be made of a magnetically conductive plastic. This can be implemented by, for example, making a strip from a magnetically conductive adhesive means. This is done by mixing magnetic powder or iron powder with adhesive means and locating said adhesive means precisely in position between the first side of the saddle coil and the measuring tube.

**[0022]** The element is preferably co-encapsulated with the measuring tube, during which encapsulating process the element can be embedded in the measuring tube. The saddle coil is then attached, for example secured by adhesive means, to the measuring tube and the aggregate formed in this way then inserted into an outer tube. This is followed by a second encapsulating process. When the mentioned parts have been embedded in the sealing compound and this has cured, then all the parts will be correctly mutually positioned and there will be no risk of this positioning's being altered by external influences.

**[0023]** The element is preferably extended transversally to the direction of flow such that a measuring error will be minimal. As mentioned above, the function of the element is to bring the magnetic field generated by the saddle coil closer to the electrode, with there here being a point having maximum magnetic flux density. Said point is displaceable with the length of the element transversally to the direction of flow or, expressed more precisely, circumferentially to the measuring tube or tangentially to the measuring tube. The longer the element is, the closer the point will be to the

electrode, and the measuring error will almost be eliminated if the length is correct. The length of the element determines the linearity of the measuring result and the "best" length is hence the length that will result in the smallest linearity error. If, conversely, too great a length is selected, other errors will result. Only a small part of the magnetic flux of the entire saddle coil passes through the element, but said small part is locally concentrated by the element.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The invention is described in more detail below with reference to the preferred exemplary embodiments in conjunction with the drawing, in which:

Fig. 1 is a schematic elucidating the operating principle of a magnetically inductive flow meter,

Fig. 2 is a part-sectional schematic of a flow meter,

Fig. 3 is a partial view from Fig. 2,

Fig. 4 shows a modified embodiment corresponding in view to Fig. 3,

Fig. 5 shows a third embodiment of a magnetically conductive element,

Fig. 6 is a schematic elucidating the dysfunctional behavior, and

Fig. 7 shows various field curves.

DETAILED DESCRIPTION OF THE INVENTION

[0025] Fig. 1 shows a magnetically inductive flow meter 1 having a measuring tube 2 through which a fluid, which is to say a gas or liquid, can flow in the axial direction, which is to say in a direction of flow 3. Located on the measuring tube 2 are two mutually opposite saddle coils 4 to which current is applied such that they generate a magnetic field 5 symbolized by an arrow. The magnetic field 5 is substantially perpendicular to the direction of flow 3. The magnetic field 5 is not, of course, concentrated on one line but ideally extends over the entire cross-section of the measuring tube 2.

[0026] An electrode array, one electrode 6 in which is shown in the measuring tube 2, is arranged in such a way that a voltage 7, symbolized by an arrow, can be tapped substantially perpendicularly to the magnetic field 5 and substantially perpendicularly to the direction of flow 3 when the fluid moves. The magnitude of the voltage 7 is a measure of the speed of flow and hence a measure of the flow rate of the fluid through the measuring tube 2.

[0027] The saddle coils 4 are embodied in the plan view (which is to say viewed in a direction parallel to the magnetic field 5) as substantially rectangular, with there being two first coil sides 8 extending parallel to the direction of flow 3 and two second coil sides 9 accommodated to the curvature of the measuring tube 2. It is thereby possible to bring the saddle coils 4 relatively close to the measuring tube 2 and to generate a magnetic field despite this. A pole shoe or yoke is not necessary for this, however. The first and second coil

sides can extend linearly or they can have a plurality of linear sections mutually enclosing angles.

**[0028]** Fig. 2 is an enlarged sectional view of substantial parts of the flow meter 1. A section in the plane in which the electrodes 6 are located is illustrated in Fig. 2.

**[0029]** The electrodes 6 are surrounded by a schematically shown terminal housing 10. Said terminal housing 10 prevents the first sides 8 of the saddle coils 4 from being able to approach the electrode 6, which is to say a clear gap remains between the first sides 8 of the saddle coil 4 and the electrode 6. A magnetic field will consequently form that is strongly attenuated toward the electrode 6. A field line 11 of said magnetic field has been drawn as a dashed line to elucidate this. Said field line 11 is a relatively large distance from the electrode 6.

**[0030]** A magnetically conductive element 12 has been inserted into a gap 13 between the first side 8 of the saddle coil 4 and the measuring tube 2 in order to eliminate this problem. Said element 12 has a length L in the circumferential direction or transversally to the direction of flow 3, which is to say it proceeds from the inner edge 14 of the first coil side 8, extends throughout the length L below the first coil side 8, and terminates between the first side 8 and the measuring tube.

**[0031]** The magnetically conductive element 12 then changes the magnetic field in such a way that it moves closer to the electrode 6. For this purpose a field line 15 is shown at

which the magnetic field has the same field strength as without the element 12 on the previously discussed field line 11. A point of intersection P of the field line 15 with the measuring tube 2 is moved further toward the electrode 6. The measuring signal then increases, as desired. A point P having a maximum magnetic flux can be found by means of a suitable length L, which is to say the extent of the element in the circumferential or tangential direction of the measuring tube 2. Said point can be moved with the length L of the element 12. The longer the length L is, the closer the point P will be to the electrode 6.

**[0032]** Only a small part of the magnetic flux of an entire saddle coil 4 passes through the element 12, but that part of the magnetic flux will be locally concentrated by the element. In contrast to this, the entire flux is routed through the pole shoe in the prior art when a pole shoe or yoke is used.

**[0033]** The measuring tube 2 is made of a magnetically non-conductive material, for example a plastic material. The magnetic field closes through an outer tube 16 surrounding the measuring tube 2, the saddle coils 4, and the terminal housing 10 of the electrodes 6. For the sake of better clarity, said tube 16 is not shown in Fig. 1. It is made of a magnetically conductive material such as soft iron, for example.

**[0034]** Figs. 3 to 5 show various possibilities for embodying the element 12. Identical and mutually corresponding parts shown here and in Fig. 2 are identically referenced. The outer tube 16 has been omitted.

[0035] In Fig. 3 the element 12 has an angled section 17 of width D. Said section 17 has virtually no magnetic function. Its sole purpose is to enable the element 12 to be secured against the first coil side 8, specifically against its inner side 14. As can be seen in Fig. 1, said inner side 14 is the side of the first coil side 8 that is surrounded by the saddle coil 4, which is to say is opposite the other first coil side 8 (not shown in Fig. 1).

[0036] The section 17 can simply be brought to rest against the first side 8 of the saddle coil. It is, however, also possible to provide an adhesive means 18 which is applied between the section 17 and the first coil side 8 and securely adheres the first section 17 to the first coil side 8. The adhesive means 18 can be embodied in the form of, for example, a double-sided adhesive strip. The adhesive means can alternatively be applied between the measuring tube 2 and the element 12 or, as the case may be, between the element 12 and the coil side 8.

[0037] In the direction of flow the element 12 extends preferably along the entire axial length of the first coil side 8, which is to say along the length between the two second coil sides 9.

[0038] Fig. 4 shows an embodiment in which the element 12 is embodied as a clip. It is for this purpose embodied as being U-shaped with the section 17 as the base and two arms 19, 20, with the arm 20 adjacent to the measuring tube 2 being longer than the arm 19 on the opposite side of the first coil side 8. The arm 19 has virtually no magnetic function, either. Its sole purpose is to securely retain the element 12 on the first

side 8 of the saddle coil 4 by a clamping action. The element 12 is for this purpose pretensioned, which is to say the arm 19 encloses together with the section 17 an angle  $\alpha$  that is somewhat smaller than the angle on the corresponding edge of the first coil side 8. The arm 20 similarly encloses together with the section 17 an angle  $\alpha'$  that is likewise somewhat smaller than determined by the geometry of the coil side 8. Intrinsic tensioning is produced thereby which securely retains the element 12 on the first coil side 8.

**[0039]** The element 12 is therefore pushed with a small force onto the first coil side 8 as a clip. The space between the outer tube 16 and the measuring tube 2 can subsequently be filled with a sealing compound so that the saddle coils 4, the elements 12, the leads, the terminal housing 10, and the electrode 6 are mechanically secured.

**[0040]** The element 12 does not have to be in mechanical contact with the saddle coil 4. It suffices if said element is attached between the saddle coil 4 and the measuring tube 2.

**[0041]** Elements 12 of this type are of course located between all four first sides 8 of the two saddle coils 4 and the measuring tube 2.

**[0042]** In a variant not shown in greater detail the element is formed from a strip of magnetically conductive adhesive means or plastic. Magnetic powder or soft iron powder, for example, is for this purpose mixed with an adhesive material and said adhesive material then located precisely in position between the first coil side 8 and the measuring tube 2.

[0043] The element 12 is, however, preferably made of soft magnetic iron. Soft magnetic iron conducts a magnetic field, as is known per se.

[0044] Fig. 5 shows a further embodiment in which an element 12, otherwise corresponding substantially to that shown in Fig. 4, has a recess 21 between its ends 22, 23 lying in the direction of flow 3. This gives rise to magnetically conductive strips 24, 25 which route the magnetic field to a distributor strip 26. By means of this embodiment a magnetic field is generated that is distributed somewhat around the point P.

[0045] It can also be provided in a manner not shown in greater detail for the surface of the element 12 to be undulated, or for the element 12 itself to be undulated. The structure could be, for example, sinusoidal.

[0046] Fig. 6 is a schematic showing the effects of the element 12. A curve 27 illustrates a relative error X across the flow F. It can be seen that the measuring error increases sharply in the case of low flow rates. In other words a low measuring signal and an increased signal-to-noise ratio will result from a too small magnetic field in the area of the electrodes 6.

[0047] A curve 28 illustrates the error curve for an element 12 of optimum length L. It can be seen that the error remains relatively small even in the case of low flow rates.

[0048] A curve 29 illustrates the situation in which an element 12 is indeed used but the length L of said element is too

great. Although the error remains smaller than without an element 12, the measuring result will not be optimal if the length L is too great.

**[0049]** The effects of the element 12 can be seen in Fig. 7. The three partial figures show the magnetic field lines, which is to say the lines having the same magnetic flux, for different embodiments. Fig. 7a shows the magnetic field when there is no element 12. It can be seen that the field-line density on the inner side of the measuring tube 2 is not all that great at the bottom edge of Fig. 7a, in any event smaller than inside the measuring tube (referred to what is shown in Fig. 7a: further to the right).

**[0050]** Fig. 7b shows a corresponding field-line scenario with an element 12. It can be seen that the field-line density in the area on the inner side of the measuring tube 2 has sharply increased.

**[0051]** The situation becomes even clearer when an element 12 having a section 17 is used. The field-line density has now become greater in the area on the inner side of the measuring tube 2 below the first coil side 8. This is shown in Fig. 7c.